ARTICLES

The Massachusetts Institute of Technology Mass Spectrometry School

Klaus Biemann

Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

The events that led to the establishment of organic and biochemical mass spectrometry at MIT by the author in 1958, and its growth over the past three and one-half decades are briefly chronicled. A major emphasis is placed on the work with graduate students and postdoctoral researchers who were educated in the field and in turn further contributed to the training of others. An attempt is made at the construction of a genealogy encompassing −7 to +2 generations (the author representing 0). *(J Am Soc Mass Spectrom 1994, 5, 332–338)*

The Special Editors of this issue have asked me to contribute a brief account of the origin and early development of the mass spectrometry group in the department of chemistry at the Massachusetts Institute of Technology (MIT). Many who are currently active in the field were members of that group at one time or another. It is a pleasure to accommodate this request, particularly as it provides an opportunity to recognize the many individuals who contributed to this laboratory's important earlier endeavors.

The phrase "to be in the right place at the right time" is appropriate for more than one instance that led to the origin and growth of the "MIT Mass Spectrometry School." The first of these was the author's attendance at a Conference on Food Flavors, held in Chicago in late 1956. Trained in synthetic organic chemistry (with H. Bretschneider at the University of Innsbruck, Austria) and later working on the synthesis and structure of natural products as a postdoc with George Büchi at MIT, I had no (scientific) interest in food flavors. However, Firmenich & Cie. (Geneva, Switzerland), who supported my work with Büchi, wanted a report covering this conference and I was happy to go to Chicago (my first airplane trip!) and take notes during the lectures.

One of these talks was by W. H. Stahl, from the U.S. Quartermaster Research and Engineering Center (in nearby Natick, Massachusetts!), who described the use of a mass spectrometer (a fancy instrument I had never heard of) to identify fruit flavor components, such as ethyl butyrate and butyl acetate, by comparing their mass spectra with data published in the collection of the American Petroleum Institute (API). At that time, I, like everyone else in organic chemistry, routinely used infrared and ultraviolet spectra for checking products of syntheses or structures of natural products, and it occurred to me that mass spectrometry might be useful for the same purpose. Thus, after sending off my report to Firmenich, I began to look into the literature for papers describing the use of mass spectrometry with organic compounds. Most of the publications dealt with the qualitative and quantitative analysis of complex hydrocarbons, an application that had made the commercial production of mass spectrometers economically attractive. The Consolidated Electrodynamics Corporation's (CEC, Pasadena, CA) models 21-101 through 103 dominated the market from the 1940s to the 1960s. However, there were publications that dealt with the correlation of the mass spectra of small heteroatom-containing compounds with their known structure in an effort to develop "fragmentation rules." For example, to name a few, there were papers on aliphatic amines by Collin [1], lactones by Friedman [2], alcohols and ketones by Friedel [3] and Sharkey [4], and a brief review by McLafferty [5]. The then beginning pioneering studies of Ryhage and Stenhagen [6] on long-chain fatty acids utilizing a similar mass spectrometer designed and built by Ryhage [7] were not yet known.

The Beginnings

About that time, A. C. Cope, the Head of the Department of Chemistry at MIT and one of the most prominent organic chemists of his day in the country, decided that because, in his mind, organic chemistry comprised 80% of all chemistry, it should also be represented in the analytical division of the department. Having taught a course in qualitative, organic analysis at the University of Innsbruck prior to coming to MIT and as I was already there (right time, right place), I was appointed as of September 1, 1957, to the position of Instructor, then the first step of the academic ladder.

Address reprint requests to Professor Klaus Biemann, Department of Chemistry, Room 56-010, Massachusetts Institute of Technology, Cambridge, MA 02139-4307.

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I now faced the dilemma that I could not base a research career in an analytical chemistry setting on what I had done previously, which was mainly organic synthesis and the determination of the structure of natural products in the conventional sense. However, it did not take long to realize that I could rearrange these fields around mass spectrometry, which would be a legitimate analytical centerpiece. The fact that I had no practical experience was an advantage, as it did not deter me, contrary to contemporary wisdom, from planning to put comparatively large and polar molecules, such as alkaloids and derivatives of amino acids and peptides, into the mass spectrometer.

The only obstacle was the lack of an instrument, which would cost $50,000–60,000 and vastly exceeded the price of other commercial instrumentation that chemists used at the time. When I asked Cope why we did not have a mass spectrometer, he replied that it would take a full-time electrical engineer to keep it running. After some persuading to the contrary, he said "OK, I will find the money for the instrument, if you promise that it will not collect dust." History shows that we both kept our promises.

In the meantime, I had maintained contact with Max Stoll, Scientific Director of Firmenich & Cie. in Geneva, regarding their interest in applying mass spectrometry to flavor and fragrances research. As a consequence, this company supported the purchase of the CEC 21-103C mass spectrometer with a gift of $10,000. In addition, Firmenich agreed to provide funds for a postdoctoral position for someone to work with me on my research projects and also measure the mass spectra of some compounds to evaluate the utility of this method in their work.

This was an important event because, by myself, I could not fully utilize the instrument, interpret the data, carry out the chemistry that needed to be done, and still fulfill my departmental duties in the analytical course cycle. Needless-to-say, the chance for an instructor working in an unknown field to get good graduate students right away was nil. Fortunately, I had kept in contact with the members of H. Bretschneider's research laboratory in Innsbruck. Therefore, I knew that Josef (Sepp) Seibl, who had worked with me in the same room in the chemistry building, was not happy with his job at a small Austrian company and that Fritz Gapp, who had been a graduate student when I left for MIT, had just obtained his Ph.D. degree and was looking for a position in the Austrian or German pharmaceutical industry. Since the instrument was scheduled to be installed in early May 1958, time was of the essence. In a flurry of correspondence, I offered the position to both, giving Seibl the preference. When he accepted, I had to send Fritz Gapp a "sorry, no" letter but a few days later I received word that my first National Institutes of Health (NIH) grant application had been approved, including funds for a postdoc. A telegram to Fritz (no fax machines in those days!) offered him that position, which he accepted at once. Sepp Seibl arrived at MIT the day the installation of the instrument began (May 7, 1958) and Fritz Gapp came soon thereafter. During the first week of June, I attended my first E-14 meeting (now the American Society for Mass Spectrometry Conference) and, to date, I have only missed one of them. Seibl and Gapp began the string of postdocs from Innsbruck, the first six on the list (Figure 1) and later Willi and Ute Richter, and finally Heinz Nau.

With two full-time, enthusiastic co-workers, things got off to a quick start. My interest in peptide sequencing predated the involvement with mass spectrometry. The last paper I had published with H. Bretschneider [8] reported the synthesis of 1,2,4-triazoles involving a carboxylic acid hydrazide as one of the reactants. While developing the NIH proposal to use this reaction to mark the carboxyl end of a peptide obtained by partial hydrazinolysis of a protein to complement Sanger's [9] labeling of the amino terminal by reaction with dinitrofluorobenzene, I had become familiar with the problems in amino acid sequencing. From my training in organic chemistry, I was, of course, also acquainted with Karrer's [10] use of $LiAlH_4$ for, amongst other applications, the preparative reduction of amido groups to amines in derivatives of di- and tripeptides. As mentioned earlier, this grant was approved but I changed the approach proposed instead to the microscale reduction of the polyamide backbone of peptides to polyamino alcohols, which were sufficiently volatile to be introduced into the somewhat modified inlet system of the CEC 21-103. This work, describing the potential for peptide sequencing, was reported in our first publication [11] in the field of mass spectrometry.

Over the next two decades this methodology was improved and refined, first by Walter Vetter, then by Hans Förster, James Kelly, and Heinz Nau, and finally applied to the sequencing of the proteins monellin [12] (with Gail Hudson) and bacteriorhodopsin [13] (with Robert Anderegg and Walter Herlihy, in collaboration with H. Gobind Khorana's research group). Soon thereafter, the invention of fast-atom bombardment (FAB) ionization [14] rendered the elaborate chemical derivatization of peptides obsolete and we switched to FAB, and later extended it to tandem mass spectrometry [15]. This work, exceeding three decades, was acknowledged by the Pehr Edman Award that was received in 1992. Also honored at the same time was Donald F. Hunt, whose career in mass spectrometry had begun in my laboratory a quarter of a century earlier.

With Seibl and Gapp fully occupied with amino acids and peptides, I had to carry out the early work in the structure determination of indole alkaloids by myself. Towards the end of my postdoc period with Büchi, I was to determine the structure of sarpagine. Since there was no one in his group to carry out this task by conventional means, I took a stab at it by mass spectrometry and succeeded [16] by correlating one of

its degradation products with that obtained from ajmaline, an alkaloid of known structure [17]. This approach became known as the "mass spectrometric shift technique." That work was presented at the IUPAC (International Union of Pure and Applied Chemistry) Conference on the Structure and Chemistry of Natural Products held in Australia in July 1960. Following the talk, Carl Djerassi asked me if I would help him in setting up his mass spectrometry laboratory at Stanford. I agreed to do so and spent part of the first quarter of 1961 teaching Herbert Budzikiewicz how to operate their newly acquired CEC 21-103C and to interpret the data. In his own account of history, Djerassi [18] states that "it was the elegant rationalization of Biemann at MIT of the mass spectral fragmentation behavior of alkaloids of the aspidospermine class that stimulated a serious effort at Stanford on organic chemical applications of mass spectrometry." Thus, one might indirectly include Carl Djerassi and all his mass spectrometry students and trainees in the extended MIT school.

The mass spectrometric determination of the structure of indole alkaloids became the research project of Gerhard Spiteller, another of the Bretschneider Ph.D.s who joined me as postdocs, along with Margot Friedmann (who later became his wife). Their work [19] resulted in the determination of the structures of a number of aspidosperma alkaloids.

The First Students

At that point in time, my research activities had reached the level of visibility that graduate students took notice. The first of these was James A. McCloskey, who had been admitted to MIT's Graduate School in 1957. After absolving his two-year duty with the U.S. Army, Jim returned in February 1961, and chose to work with me on the applications of mass spectrometry to new areas, namely, free amino acids, carbohydrates, and nucleosides. The low volatility of these compounds required designing a technique that would permit the vaporization of very polar molecules directly into the ion source of the mass spectrometer. Jim, therefore, developed and constructed direct introduction probes for both the CEC 21-103C and the Bendix time-of-flight (TOF) mass spectrometers. The latter instrument had been acquired with funds from NASA, which was interested in obtaining any information on organic compounds in an inorganic matrix. This was more easily done with the open construction of the TOF ion source. Alma L. Burlingame had entered MIT as a graduate student in 1959 with L. B. Rogers, who resigned from MIT at the end of the 1960–1961 academic year. Al then switched to my group to join the alkaloid activities in early 1961. He finished his Ph.D. slightly ahead of Jim McCloskey in 1963.

These two were followed by a number of graduate students, who sooner or later were able to pursue academic careers where the growth of organic mass spectrometry in the early 1960s provided numerous opportunities. Two reviews [20, 21] and a book [22] had appeared in 1962. The interest of organic and biological chemists was further heightened when we improved the utility of exact mass measurements developed by John Beynon's "peak matching" [23] of certain ions in the mass spectra of organic compounds. In May of 1961, we had taken delivery of a double-focusing mass spectrometer (CEC 21-110) to make use of the Mattauch-Herzog geometry of this instrument to record a complete high-resolution mass spectrum on photographic plates. The lines on the plate were then read, first by a manually operated and later by a computer-controlled densitometer. This work was briefly reported at the 1963 E-14 Conference and expanded upon a year later in Montreal, demonstrating that complete high-resolution mass spectra (i.e., elemental composition data) could be obtained from alkaloids eluting from a gas chromatography column coupled to the mass spectrometer. This set of four consecutive presentations generated a flurry of activity by other manufacturers to match this performance by using various computer-based recording techniques, the forefathers of today's data systems.

Federal Grant Support

The purchase of the CEC 21-110 mass spectrometer had been jointly funded by the National Science Foundation and NIH. By the early 1960s, the latter agency had established a new funding category, the "Training Grants," which were awarded to Principal Investigators to train graduate and postdoctoral students in areas the agency thought to be new and important. Fortunately, NIH placed high-resolution mass spectrometry in this category and asked me to apply. Upon indicating the need for an additional instrument and my own computer, it was pointed out that the data-generating capacity of that equipment and manpower would exceed the needs of my own research projects, as well as the funding usually provided by training grants. But there was yet another new category, termed "Research Facilities," for the purpose of making novel but expertise- and capital-intensive methodologies available to the "biomedical community." Thus, NIH suggested that I also apply for one of these grants. Clearly, the early 1960s was the time when NIH support was on a steeply rising incline, another instance of being in the right place at the right time. Because of this early and significant financial support, one-half of all my graduate students obtained their Ph.D. degrees between 1963 and 1975, and they include all those who presently hold senior and distinguished academic positions. A similar statement can also be made for the postdoctoral category. This training grant, thus, has paid off in an exponential fashion, even beyond its termination in 1975.

With the decline of federal funding for basic research, which hit junior people particularly hard, and the end of university faculty expansion, academic positions were more difficult to come by, not the least because of the also increasing capital cost of high-performance mass spectrometers. Fortunately, the advent of novel ionization methods and the coming-of-age of the biotechnology industry opened up a new source of challenging employment opportunities. As a consequence, a good portion of graduate students and postdocs took up leading positions in this research-minded industry. The first was Walter Herlihy, who joined the Repligen Corp. in its formative state and soon became its vice-president of research.

The "Family Tree"

Having discussed the development of my own research group, it is worthwhile to look back at our academic ancestry (Figure 1). This idea was initiated years ago by the request of William T. Cooper at Florida State (a student of John Hayes), whose department wanted to establish the academic ancestry of their faculty. It was relatively easy to go back a few steps based on my own memory and with the help of colleagues in Austria, as long as there was a documented, conventional mentor-student relationship. But before the 1850s, this relationship was not as straightforward as it is today, because then it was more of an apprenticeship. Thus, while Hlasiwetz was quite clearly a pupil of Redtenbacher, the latter's relationship to von Liebig is more diffuse. Having obtained an *M.D.* under Mohs in *botany*, which in Vienna at that time was combined with chemistry, Redtenbacher was appointed professor of *chemistry* at the University of Prague (then part of the Austrian-Hungarian Empire under Leopold II). He had felt the need to learn more about chemistry and joined von Liebig's laboratory in Giessen. Interestingly enough, the only but very extensive paper they published together [24] concerned the "exact" atomic weight of carbon by combustion of silver acetate. The result of 75.854 seems to be quite different from the present value (12.011), but is fairly accurate considering that the atomic weight of hydrogen was thought to be about 6.24 at that time. Unfortunately, unlike their descendants 120 years later, von Liebig and Redtenbacher did not have access to a mass spectrometer. According to Ernest Campaigne, Professor Emeritus in Chemistry at Indiana University, von Liebig in turn goes back to Lavoisier via Gay-Lussac and Berthollet.

Figure 1 is an attempt to put the "Family Tree" together, listing the entire first generation of students and postdocs, etc., with a numerical indication for those of the second generation. To extend further downward becomes more and more difficult for me but I hope that this article will encourage those who studied with and/or were trained by those listed in the first and third columns of Figure 1 to let me know their relationship. Since my graduate students are my (and therefore von Liebig's or even Lavoisier's) descendants, their students are part of this genealogy, regardless of whether they are mass spectrometrists or not. For example, W. T. Cooper, a student of John Hayes, Distinguished Professor of Biogeochemistry at Indiana University, already has his own crop of graduate students who, therefore, represent the third generation. On the other hand, postdoctoral associates have their own academic lineage but may be included in the MIT School of Mass Spectrometry. For their students and postdoctoral or other associates, only those trained in mass spectrometry and with continuous substantial activity in this field should be counted. To use John Hayes again as an example, only those 21 of his total of 36 postdoctoral associates whom he trained in mass spectrometry, rather than other areas of biogeochemistry, are considered members of the extended MIT School. In Figure 1, this distinction is made by listing the number of students first, followed by the number of other associates trained in mass spectrometry, separated by a slash. At last count, I had (or have) 54 students. They in turn had 180 students, for a total of 234 (counting only the first and second generations) who thus go back to von Liebig.

The 83 postdoctoral associates, visiting scientists (more than three months), and those technical assistants who pursued a permanent career in mass spectrometry (Figure 1) trained a total of 231 graduate students and 98 postdoctoral associates, etc., in mass spectrometry, while my own graduate students trained 289 in the latter category. Thus, at present, the MIT School of Mass Spectrometry numbers 937 members, not including third and further generations which would put it well over one thousand. Of course, there are a few duplications, as some of my postdoctoral associates (e.g., Mathews, Pang, Kassel, Annan, and Ghosh) were Ph.D. students of my own graduate students (Murphy, McCloskey, Watson, Vouros, and Anderegg), but their number is probably compensated by inadvertent omissions in the second generation.

Finally, it is noteworthy that a number of my students and associates have been active in various elective positions of the American Society for Mass Spectrometry. Three of these (McCloskey, Hites, and Murphy) then served as Presidents of the Society. Under the leadership of one of them (R. A. H.) this Journal was established.

Conclusion

This account reveals some of the ingredients important for the success of an academic career: (1) the advantage of entering a new, largely unexplored field, which in this case was triggered by hearing (accidentally) about mass spectrometry from the lecture of W. H. Stahl, and combining that information with one's own, quite different scientific background; (2) not to be deterred by difficulties that may be preconceived by

STUDENTS*

12/39 James Augustus McCloskey, Ph.D. '63
12/66 Alma Lyman Burlingame, Ph.D. '63
Dennis Howard Smith, B.S. '64
13/8 Heinrich Konstantin Schnoes, Ph.D. '65
24/8 Jack Throck Watson, Ph.D. '65
29/9 Paul Vouros, Ph.D. '65
Julieta Moran - Barron, S.M. '65
3/17 Dominic Morse Desiderio, Ph.D. '66
20/21 John Michael Hayes, Ph.D. '66
David William Thomas, Ph.D. '67
Robert Berj Gagosian, B.S. '67
0/21 Sanford Philip Markey, Ph.D. '68
2/5 Paul Vincent Fennessey, Ph.D. '68
36/20 Ronald Atlee Hites, Ph.D. '68
Charles Ewell Hignite, Ph.D. '69; P.D. '69-74
Bonnie March King, B.S. '69
James Robert Althaus, Ph.D. '70
9/18 Robert Carl Murphy, Ph.D. '70
0/2 George Preti, Ph.D. '71
2/5 Harry Steven Hertz, Ph.D. '71
0/5 James Anthony Kelly, Ph.D. '72
James Edward Biller, Ph.D. '72; P.D. '72-75; R.S. '75-
John Joseph Dolhun, Ph.D. '73
Arthur Lucien Lafleur, Ph.D. '73
Brian Dean Andresen, Ph.D. '74
Tyrone Ralph Smith, Ph.D. '75
5/23 Lan Kan Wong, Ph.D. '77
10/1 Robert James Anderegg, Ph.D. '77; P.D. '77-79
Gail Ann Hudson, Ph.D. '77
Olga Nakamine de Wong, S.M. '77
John Milan Lavoie, Ph.D. '79
Walter Curtin Herlihy, Ph.D. '79; P.D. '79-80; R.S. '80-81
Linda Jean Anthony, Ph.D. '80
0/2 Steven Alfred Carr, Ph.D. '81; P.D. '81-82
Agnes Marie Van Langenhove, Ph.D. '81
David Allan Kidwell, Ph.D. '82
Nancy Jean LeGendre, Ph.D. '82
Kin Sing Chiu, Ph.D. '83
Hwa-Fu Chen, S.M. '83
5/4 Bradford Wayne Gibson, Ph.D. '84
John Charles Karris, S.M. '84
0/10 Julie Ann Leary, Ph.D. '84
0/3 Stephen Alfred Martin, Ph.D. '85; P.D. '85-86; R.S. '88-89
Ioannis A. Papayannopoulos, Ph.D. '87; P.D. '87-90; R.S. '90-93
John Joseph Gagel, Ph.D. '88
Richard Scott Johnson, Ph.D. '88
Eric Henry Block, S.M. '88
James Edward Vath, Ph.D. '90
James Amherst Hill, Ph.D. '92; P.D. '92-
Joseph Zaia, Ph.D. '93; P.D. '93-
Chenhui Zeng, G.S. '90-
Heinrich Josef Köchling, G.S. '90-
Vladimir V. Papov, G.S. '90-
Andrew Rhomberg, G.S. '93-

Justus von Liebig
(1803 - 1873)
Ph.D. Chemistry
Univ. of Erlangen, 1822
Prof. of Chemistry, Univ. of Giessen

↓

Josef Redtenbacher
(1810 - 1870)
M.D. (Botany, under Mohs)
Univ. of Vienna, 1834
Prof. of Chemistry
Univ. of Prague, 1840
Trained with von Liebig in Chemistry
Univ. of Giessen, 1839-1841

↓

Heinrich H.C. Hlasiwetz
(1825 - 1875)
Ph.D. Chemistry
Univ. of Prague, 1849
(moved to Univ. of Innsbruck, 1851)

↓

Ludwig Barth von Barthenau
(1839 - 1890)
Ph.D. Organic Chemistry
Univ. of Innsbruck, 1860
(moved to Univ. of Vienna, 1876)

↓

Rudolf F. Wegscheider
(1859 - 1935)
Ph.D. Organic Chemistry
Univ. of Vienna, 1882

↓

Ernst Späth
(1886 - 1946)
Ph.D. Organic Chemistry
Univ. of Vienna, 1910

↓

Hermann Bretschneider
(1905 - 1985)
Ph.D. Organic Chemistry
Univ. of Vienna, 1928

↓

Klaus Biemann
(1926 -)
Ph.D. Organic Chemistry
Univ. of Innsbruck, 1951

Figure 1. Academic genealogy of the author and the names and years of graduation of his students and the names of postdoctoral and other trainees with the period of their stay at MIT. The numbers preceding some of the names are that individual's own students and postdoctoral associates, respectively (see text). *G.S. = Graduate Student; P.D. = Postdoctoral Associate/Fellow; R.S. = Research Scientist/Staff; T.A. = Technical Assistant; V.S. = Visiting Scientist.

POSTDOCTORAL ASSOCIATES, etc.*

22/11	Josef Seibl, P.D. '58-60
	Fritz Gapp, P.D. '58-59
	Walter Vetter, P.D. '59-62
77/3	Gerhard Spiteller, P.D. '60-61
	Margot Friedmann-Spiteller, P.D. '60-61
	Helga Diechtl-Vetter, P.D. '60-62
	Gottfried G.J. Deffner, P.D. '61-62
	Wolfgang Benz, P.D. '62-63
19/10	Bhupesh Das, P.D. '62-64
10/3	Don C DeJongh, P.D. '62-63
	David B. MacLean, V.S. '62-63
2/5	Wilhelm J. Richter, P.D. '62-64
	Ute S. Richter, P.D. '62-64
	Georg E. Albers-Schönberg, P.D. '63-65
	Peter Rommer, P.D. '63-65
0/2	John L. Occolowitz, V.S. '63-64
0/2	Walter J. McMurray, P.D. '63-64
	Chris Falshaw, P.D. '64
	William Hargrove, V.S. '64
	Hans Achenbach, P.D. '64-65
	Sukenari Tsunakawa, V.S. '64-66
	Brian R. Webster, P.D. '64-65
	Pierre Witz, P.D. '64-65
	Shigenobu Okuda, V.S. '65
	Guy P. Arsenault, V.S. '65-66; R.S. '67-77
	Norman Mancuso, P.D. '65-79
	Conrad Cone, P.D. '65-68
	Istvan Lengyel, P.D. '65-67
	Robert Lovins, P.D. '65-69
	Helmut Seidl, P.D. '65-67
6/1	Fabrizio Bruner, P.D. '66-68
	John Edgar, P.D. '66-67
	Agnes Jacquesy, P.D. '66-67
19/3	Asher Mandelbaum, P.D. '66-68
0/4	Lubomir Baczynskyj, P.D. '67-68
	David A. Evans, P.D. '67-69
45/10	Donald F. Hunt, P.D. '67-68
	Ray Salamone, P.D. '67-69
	August Curley, V.S. '68
	Steven Hecht, P.D. '68-69
3/16	Vernon N. Reinhold, P.D. '68-71
	Shang-Wai Tam, P.D. '68-69
	Paul Donaghue, P.D. '69-70
0/3	Hans-Joachim Förster, P.D. '69-72
	M.-Mehdi Nafissi-Varchei, P.D. '69-70
	Milica Djuricic, P.D. '70-72
22/21	Heinz Nau, P.D. '70-74
	Toshio Sakai, V.S. '70-72
	Catherine E. Costello, P.D. '70-75; R.S. '75-
	Ferdinand Wirtz-Peitz, P.D. '71-72
	Leonard C.-C. Wan, P.D. '72-74
	Abdul M. Choudhury, P.D. '75-76
	Bary W. Wilson, P.D. '76-78
1/0	Pierre Borgeat, P.D. '77
	Andrew Schkuta, T.A. '78-80
	Robert A. Bethem, T.A. '78-79, '80-82
	Linda (Li) Ng, P.D. '79-80
	Michel A. Lhermitte, V.S. '79
	Koka Jayasimhulu, P.D. '79-80
	W. Rodney Mathews, P.D. '81-84; R.S. '84-85
	Asao Murai, V.S. '82
	Thomas F. Dorsey, T.A. '82-85
	Henrianna Y. Pang, P.D. '82-84
	Hubert A. Scoble, P.D. '82-85; R.S. '85-86
	Markus Zollinger, P.D. '83-85
	Simin D. Maleknia, T.A. '83-86,'90-92; P.D. '92-93
	Mamoru Fujioka, V.S. '84-85
2/2	Günter Allmaier, P.D. '85-86
	Bruno Domon, P.D. '86-87
3/3	Achille Cappiello, P.D. '87-89
	Pierangela Palma, P.D. '87-89
	Daniel B. Kassel, P.D. '88-89
	Adam S. Plaziak, P.D. '89-90
	Wade J. Adams, V.S. '89-90
	Roland S. Annan, P.D. '89-92
	Amit Ghosh, P.D. '89-91
	Alain Jaquier, V.S. '90-91
	Peter Juhasz, P.D. '90-93; R.S. '93-
	Kevin M. Downard, P.D. '91-
	Peter M. Gehrig, V.S. '92-
	Hélène Perreault, P.D. '92-
	Binghuang Wang, P.D. '92-93
	Yoon-Seok Chang, P.D. '92
	Stephan Apfalter, V.S. '92-93

Figure 1. Continued.

the practitioners of that time; (3) to have associates and students who are enthusiastically following that new direction; and last, but not least, having some luck at being in the right places at the right times.

Apologies

The author takes full responsibility for any inaccuracies, omissions, and false claims, but would like to be made aware of them.

Pleas

As mentioned earlier, it would be appreciated if those who obtained their academic or mass spectrometric training from descendants of my graduate students or postdoctoral associates, etc., would inform me of their names, present affiliation, and relationship. More importantly, I would be grateful for copies of photographs taken of individuals or equipment in my laboratory, because I myself never took any and John Hayes and Shirley Sze (a masterful operator of the computer-controlled densitometer) were the only camera-bugs around. Fortunately, I kept all my correspondence, which permitted me to reconstruct the exact dates for some of the early events.

Acknowledgment

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References

1. Collin, J. *Bull. Soc. Roy. Sci. Liège* **1952,** *21,* 446.
2. Friedman, L.; Long, F. A. *J. Am. Chem. Soc.* **1953,** *75,* 2832.
3. Friedel, R. A.; Shultz, J. L.; Sharkey, A. G. *Anal. Chem.* **1956,** *28,* 926.
4. Sharkey, A. G.; Shultz, J. L.; Friedel, R. A. *Anal. Chem.* **1956,** *28,* 934.
5. McLafferty, F. W. *Anal. Chem.* **1956,** *28,* 306.
6. Ryhage, R.; Stenhagen, E. *Arkiv Kemi* **1959,** *13,* 523.
7. Ryhage, R. *Arkiv Kemi* **1959,** *13,* 475.
8. Biemann, K.; Bretschneider, H. *Monatsh. Chem.* **1958,** *89,* 603.
9. Sanger, F. *Biochem. J.* **1945,** *39,* 507.
10. Karrer, P.; Nicolaus, B. J. R. *Helv. Chim. Acta* **1952,** *35,* 1581.
11. Biemann, K.; Gapp, F.; Seibl, J. *J. Am. Chem. Soc.* **1959,** *81,* 2274.
12. Hudson, G.; Biemann, K. *Biochem. Biophys. Res. Commun.* **1976,** *71,* 212.
13. Khorana, H. G.; Gerber, G. E.; Herlihy, W. C.; Gray, C.; Anderegg, R. J.; Nihei, K.; Biemann, K. *Proc. Natl. Acad. Sci. USA* **1979,** *76,* 5046.
14. Barber, M.; Bordoli, R. S.; Sedgwick, R. D.; Tyler, A. N. *J. Chem. Soc. Chem. Commun.* **1981,** 325.
15. Biemann, K. *Anal. Chem.* **1986,** *58,* 1289A.
16. Biemann, K. *Tetrahedron Lett.* **1960,** *15,* 9.
17. Woodward, R. B. *Angew. Chem.* **1956,** *68,* 13.
18. Djerassi, C. *Org. Mass Spectrom.* **1992,** *27,* 1341.
19. Biemann, K.; Spiteller-Friedmann, M.; Spiteller, G. *J. Am. Chem. Soc.* **1963,** *85,* 631.
20. Biemann, K. *Angew. Chem.* **1962,** *74,* 102; International Ed. **1962,** *1,* 98.
21. Biemann, K. In *Modern Methods of Plant Analysis VI;* Tracey, M., Ed. Springer: Heidelberg, 1962; p. 26.
22. Biemann, K. *Mass Spectrometry: Organic Chemical Applications;* McGraw-Hill: New York, 1962.
23. Beynon, J. H. *Mass Spectrometry and Its Applications to Organic Chemistry;* Elsevier: Amsterdam, 1960.
24. Redtenbacher, J.; Liebig, J. *Annal. der Chem. und Pharm.* **1841,** *38,* 113.